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ABSTRACT

In educational effectiveness research, multilevel models are increasingly used because these models take the multilevel structure of the data into account. In this paper, the effect of ignoring one or more levels of variation in hierarchical linear regression is explored, using a model with four hierarchical levels (individual pupil, class group, teacher, and school) as a reference model. A distinction was made between ignoring the top or intermediate levels on the fixed and random parameters of different random intercept models with a real data set consisting of 2,680 Flemish (Belgian) secondary school students. Results show that ignoring the top level causes an overestimation of the variance belonging to the highest level considered. Ignoring an intermediate level causes an overestimate of the variance belonging to the level just above and that just below the level considered. The standard error of the variance estimate of the highest level considered (ignoring a top level) or of the level just under the ignored intermediate level is overestimated, while the standard error of the variance estimate to the intercept estimate seems to be underestimated in models with ignored levels. In addition, ignoring the top level can cause unstable regression coefficient estimates for the exploratory variables belonging to the highest level considered, while ignoring an intermediate level can cause unstable regression coefficient estimated of the exploratory variables belonging to the level just above and just under the level ignored. It is concluded that ignoring an important top or intermediate level can lead to different research conclusions. An appendix contains a list of the variables considered. (Contains 13 tables and 9 references.) (SLD)

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The importance of identifying levels in multilevel analysis: an illustration of the effects of ignoring the top or intermediate levels in school effectiveness research

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ABSTRACT

In educational effectiveness research, multilevel models are increasingly used because these models take the multilevel structure of the data into account. In this paper, the effect of ignoring one or more levels of variation in hierarchical linear regression analysis is explored. We used a model with four hierarchical levels (the individual pupil, the class group, the teacher and the school) as reference model and we made a distinction between ignoring the top and the intermediate levels. We explored the effects of ignoring the top or the intermediate levels on the fixed and random parameters of different random intercept models by means of a real data set. The results show that ignoring a top level causes an overestimation of the variance belonging to the highest level considered. The variance of the other levels is unaffected. Ignoring an intermediate level causes an overestimation of the variance belonging to the level just above and the level just under the level ignored. Thus, ignoring levels results in a different attribution of the variance to the levels. The standard error of the variance estimate of the highest level considered (ignoring a top level) or of the level just under the ignored intermediate level is overestimated, whereas the standard error of variance estimate of the level just above the ignored intermediate level is underestimated. Also the standard error of the intercept estimate seems to be underestimated in models with ignored levels. It is notable that the regression coefficient estimates of the explanatory variables 'at the affected level(s)' in models ignoring one or two levels differ from those obtained from the four-level model. However, the estimates of exploratory variables of the non-affected levels do not differ from those of the four-level model considered. Ignoring the top level can cause unstable regression coefficient estimates for the exploratory variables belonging to the highest level considered, while ignoring an intermediate level can cause unstable regression coefficient estimates of the exploratory variables belonging to the level just above and the level just under the level ignored. We conclude that ignoring an important top or intermediate level can lead to different research conclusions.

INTRODUCTION

In educational effectiveness research, multilevel models are increasingly used because these models take the multilevel structure of the data into account. In multilevel research, the data structure in the population is often hierarchical (e.g., pupils in schools) and the sample data are viewed as a multistage sample from their hierarchical population. In such samples, the individual observations are generally not completely independent because of selection processes and because of the common history they share by belonging to the same group (Hox, 1994). As a result, the traditional OLS regression analysis (and ordinary significant tests) with the individual as the unit of analysis may not be used because the important assumption of independence of residual error terms is violated (Hox & Kreft, 1994). Multilevel models take these dependencies into account

The identification of a level above the individual level implies the existence of different levels of variation: if there are effects of the social context (the group level) on individuals, these effects must be mediated by intervening processes that depend on the characteristics of the social context. Groups can have a main effect on individuals (different intercepts) or there can be cross-level interaction effects (different slopes). The latter requires the specification of

processes within individuals that cause those individuals to be differentially influenced by certain aspects of the context.

However, what are the criteria for choosing levels and the number of levels? There are three kinds of criteria: the theory under investigation (Hox, 1994; Snijders & Bosker, 1998) or the research question; the kind of sampling used (cf. multistage sampling) (Hox, 1994; Snijders & Bosker, 1998); or the number of units belonging to a level e.g., when there are only three units in the highest level, it makes no sense to consider that level in the analysis. Sometimes, none of the criteria can be used to determine the (number of) levels. The international literature about multilevel modeling has paid a lot of attention to the importance of identifying a level above the individual level e.g., the comparisons between multilevel modeling and ordinary least squares regression analysis (Goldstein, 1995; Longford, 1993). However, very few or no attention is paid to the determination of (the number of) levels or to the effect of ignoring one or more levels in the analysis.

PURPOSE OF THE STUDY

In this paper, the effect of ignoring one or more levels of variation in hierarchical linear regression analysis is explored. We used a model with four hierarchical levels (the individual pupil, the class group, the teacher and the school) as the reference model (PCTS). We made a distinction between ignoring the highest level (the school level), the highest two levels (the school and the teacher level) and ignoring one or two intermediate levels (the teacher and/or class level). This resulted in six other models: the pupil-class-teacher model (PCT), the pupil-class-school model (PCS), the pupil-teacher-school model (PTS), the pupil-class model (PC), the pupil-teacher (PT) and the pupil-school model (PS). The effects of ignoring levels on the fixed and random parameters of multilevel models are addressed. In this contribution we restrict the exploration to random intercept models.

DATA SOURCES AND METHOD USED

The reported data in this contribution stem from the 'Longitudinaal Onderzoek Secundair Onderwijs (LOSO)' project (longitudinal research in secondary education project) of Van Damme et al. (1997a,b) and is funded by the Department of Education of the ministry of the Flemish Community. The data set consists of longitudinal data on pupils and secondary schools in Flanders (Belgium) studied for a period of seven years. The sample of pupils is taken from almost all schools with a first grade in three regions. The schools are to a certain extent representative of the schools in Flanders: the courses offered and the distribution of the pupils over the courses of study in these three regions together are comparable to the situation in Flanders. We used information on the individual pupil (numerical intelligence), the class group (mean numerical intelligence), the teacher level (mathematics teacher's reports of instructional approach) and the school level (teachers' reports of instructional approach and school life). An overview of the variables is given in the appendix. In our analyses, we used a sample of 2680 pupils following the general track in the first year of secondary education (grade 1A) and belonging to 150 classes, 81 mathematics teachers and to 46 secondary schools. All pupils entered secondary education for the first time. Mathematics achievement at the end of the common first grade (general track) is the dependent variable in our analyses.

To analyze the data, the computer program MLn (Rasbash & Woodhouse, 1995) for multilevel analysis was used. By manipulating the number of levels and the kind of level ignored (top level or intermediate level) and comparing the results of these models with the four-level model, we investigated the implications of ignoring levels of variation. Firstly, the implications of ignoring levels on the variance structure will be addressed. The null-model solution of a four-level model will therefore be compared with the solutions of different three- and two-level models. Secondly, explanatory variables at different levels will be added to the models. The three- and two-level models will be analyzed and compared with the four-level model to show the effect of ignoring levels on the fixed regression coefficients of independent variables. To compare the fixed and random parameters of the three- and two-level models with the parameters of the four-level models, we calculated the difference between the relevant parameter of the four-level model and the parameter of the model we wanted to compare this with. We divided this difference by the standard error of the parameter of the four-level model. [1]This procedure is comparable with calculating confidence intervals around the parameter estimate of the four-level model. It gives an impression of the difference between numerical values from a statistical point of view.

RESULTS

The analysis of the four-level null model revealed that each level is important: 54.42% of the overall variance in mathematics is linked to the individual level, 14.71% to the class level, 18.07% to the teacher level and 12.81% to the school level. The four-level null model fits the data better than all the other null models do: the difference between deviance of the four-level model and of the other models is always significant at least at the five-percent level (see tables 2 and 3).

(Insert table 1)

Effects of Ignoring Levels on the Fixed and Random Parameter Estimates of Null Models

In a first step we investigated the effects of ignoring one or two <u>top levels</u>. We used three models: the pupil-class-teacher-school model (PCTS), the pupil-class-teacher model (PCT) and the pupil-class model (PC). First, null models (with no explanatory variables) are fitted to provide estimates of the components of the total variation at each level.

(Insert table 2)

Table 2 shows that ignoring a top level causes an overestimation of the variance belonging to the highest level considered. The variance of the other levels is unaffected. The standard error of the intercept seems somewhat underestimated in models where the top level is ignored. This is true in particular for the PC model. In contrast with this, the standard error of the variance estimate belonging to the highest level considered is overestimated. Again, the greatest differences are found between the four-level model and the PC model.

[1] A similar method was used by Snijders and Bosker (1998). They compared the parameter estimates of a random intercept model with the results of an ordinary least squares (OLS) regression analysis.

Ignoring an <u>intermediate level</u> (see table 3) causes an overestimation of the variance belonging to the level just above and the level just under the level ignored. As with the results of ignoring a top level, the standard error of the intercept seems to be somewhat underestimated in the models where an intermediate level is ignored. The standard error of the variance estimate belonging to the level just under the intermediate level ignored is somewhat overestimated, while the standard error of the variance estimate belonging to the level just above the intermediate level ignored is somewhat underestimated. The greatest differences were found between the four-level model and the models where the class or the class and the teacher level is ignored (the PTS and the PS model).

(Insert table 3)

Thus, ignoring levels results in a different attribution of the variance to the levels considered and can therefore lead to different research conclusions.

Effects of Ignoring Levels on the Parameter Estimates of Models with Explanatory Variables

In a second step of our exploration, explanatory variables were added to the models. All independent explanatory variables were centered around the grand mean of their corresponding level. By doing so, the computer calculations are easier and the parameters are estimated at sensible choices of locations without modeling a different model than the raw scores model (Opdenakker & Van Damme, 1997).

In the first part of this paragraph, we will discuss the effects of ignoring one or two top levels on the fixed parameter estimates of exploratory variables. Secondly, the standard errors of the fixed parameter estimates are investigated. In the last part, the random parameter estimates are addressed. The same approach is used for the discussion of the effects of ignoring one or two intermediate levels.

The case of ignoring top levels

First, the numerical intelligence of the pupils (NIQ) was added at the pupil level to the PCTS model and the PCT and the PC model (see table 4). Next, the class mean numerical intelligence (CLNIQ) at the class level was also added to the models (see table 5). The PCTS and PCT models were also fitted with NIQ, CLNIQ and teacher variables together (see table 6), and with NIQ and teacher variables alone (see table 7).

Tables 4-7 indicate that the parameter estimate of the pupil-level variable NIQ was never affected by ignoring one or two top levels.

(Insert table 4)

The parameter estimate of the class-level variable CLNIQ was only once weakly 'affected' (see table 5 and 6). This was in the case of the PC-model with ignoring the school and the teacher level. Remember that we found also that the variance of the class level differed between the four-level null model and the PC null model.

(Insert table 5)

Tables 6 and 7 indicate that the numerical values of the parameter estimates of the teacher-level variables can be different between the four-level model and the model ignoring the school level (see tables 6 and 7). From a statistical point of view we see that the estimates of a few teacher variables are weakly affected.[2] Also in this case the variance at the teacher level differed between the four-level null model and the null model ignoring the school level.

(Insert table 6 and 7)

The standard errors of the explanatory variable estimates are hardly affected by ignoring a top level. In accordance with the conclusions of the null models, the standard errors of the intercept estimates seem somewhat underestimated. The estimates of the variance belonging to the highest level considered are overestimated and the corresponding standard errors are also somewhat overestimated.

The case of ignoring intermediate levels

In tables 8 until 13 the effects of ignoring intermediate levels on the fixed parameter estimates of exploratory variables are presented.

In three models i.e. PS-, PTS- and PT-model, the estimate of the NIQ pupil variable regression coefficient is strongly different from the estimate obtained in the four-level model (see table 8, 11, 12 and 13). In all cases the estimates of the models ignoring levels differ by more than two standard errors from the estimate of the four-level model. Table 3 showed that the variance at the pupil level of the corresponding null models differed from the four-level null model.

(Insert table 8)

The class-level variable CLNIQ had a slightly different regression coefficient in the four-level model than in the model ignoring the teacher level (see tables 9 and 10).

(Insert table 9 and 10)

The majority of the teacher-level variables estimates of the models ignoring the class and/or the school level differed numerically from the ones obtained with the four-level model. (see tables 11 and 12). Sometimes, a variable is significant in the four-level model e.g., 'TSUBJMOR' is significant at 0.03 level one sided test, while this variable is not significant at all (p=0.117 one sided test) in the PT-model (see table12). However, from a statistical point of view, only a few school-level variables have different estimates. Because of the limited number of teachers in our sample, we think that the differences between the models may be underestimated.

(Insert tables 11 and 12)

Information about the school-level variables estimates are given in tables 12 and 13. In this case it is possible to compare the estimates of the four-level model with models with 'affected' school-level variance (models PCS and PS) on the one hand and with a model without affected

[2] It is possible that the estimates of the teacher-level variables seem only weakly affected because of 'large' standard errors. These large standard errors could be caused by the limited number of teachers (n=81) in our sample because the standard error, in addition to the standard deviation, is also function of the sample size.

school-level variance (PTS) on the other. The differences in school-level variables estimates are the greatest between models with 'affected' school-level variance and the four-level model. Again, from a statistical point of view, only a few estimates differ between the models. Our remark in the case of teacher variables is even more true here: the limited number of schools (n=46) could possibly cause an underestimation of the differences between the estimates.

As with ignoring a top level, ignoring an intermediate level does not affect the standard errors of the explanatory variable estimates. Only the standard error of the intercept is somewhat underestimated. The estimates of the variance belonging to the level just above and just under an intermediate level ignored are overestimated. The standard error of the variance estimate just under the level ignored is also overestimated, whereas the standard error of the variance estimate just above the level ignored is underestimated.

CONCLUSIONS

In this study we explored the effects of ignoring top or intermediate levels on the fixed and random parameters of different random intercept models. The results show that ignoring the top level causes an overestimation of the variance belonging to the highest level considered. The variance of the other levels is unaffected. Ignoring an intermediate level causes an overestimation of the variance belonging to the level just above and the level just under the level ignored. The standard error of the variance estimate of the highest level considered (ignoring a top level) or of the level just under an ignored intermediate level is overestimated, whereas the standard error of the variance estimate of the level just above the level ignored is underestimated. Also the standard error of the intercept estimate seems underestimated in models with ignored levels. Thus, ignoring levels results in a different attribution of the variance to the levels. A noteworthy result is also the finding that the regression coefficient estimates of the explanatory variables 'of the affected level(s)' in models ignoring one or two levels differ from the ones obtained from the four-level model. However, the estimates of exploratory variables of non-affected levels do not differ from the ones of the four-level model considered. Ignoring a top level can cause unstable regression coefficient estimates of the exploratory variables belonging to the highest level considered, while ignoring an intermediate level can cause unstable regression coefficient estimates of the exploratory variables belonging to the level just above and the level just under the ignored level. Based on our research, ignoring an important top or intermediate level could lead to different research conclusions. Therefore, it is recommended that users of multilevel analysis pay enough attention to the determination of (the number) levels.

Our study was a first attempt to investigate the effects of ignoring levels. There are a few limitations e.g., we did not use simulation research, our sample of teachers and schools was limited and we restricted our investigation to random intercept models. However, we used a real data set and could therefore see the possible implications of ignoring a level in a real school effectiveness research study. The results make clear the importance of further research on this topic. We make a plea for simulation research (with larger data sets on the levels above the pupil level) to investigate the circumstances under which ignoring levels can cause wide differences between a model with all the levels taken into account and models ignoring one or more levels.

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Table 1. Results for the four-level null model

	PCTS Estimate	SE	% total variance
Fixed parameters			
Intercept	43.08	1.235	
Random parameters			
School level	29.11	16.42	12.81
Teacher level	41.08	15.65	18.07
Class level	33.43	6.879	14.71
Pupil level	123.7	3.478	54.42
Deviance	20884.9		

Table 2. Results for the four-level null model and for models ignoring one or two top levels

	PCTS		*PCT*		*PC*	
	Estimate	*SE*	*Estimate*	*SE*	*Estimate*	*SE*
Fixed parameters						
Intercept	43.08	1.235	43.65	1.095	44.12	0.8648∇∇
Random parameters						
School level	29.11	16.42				
Teacher level	41.08	15.65	71.54***(*)	15.69		
Class level	33.43	6.879	33.43	6.89	104.7****	12.94ΔΔ
Pupil level	123.7	3.478	123.7	3.478	123.7	3.478
Deviance	20884.9		20890.1		20929.1	

Diff = | $estimate_{PCTS}$ - $estimate_{OM}$ | /SE_{PCTS}

. 0,675 ≤ Diff < 0.84 (0.5 ≥ p > 0.4 two sided test); ° 0.84 ≤ Diff < 1.035 (0.4 ≥ p > 0.3); * 1.035 ≤ Diff < 1.28 (0.3 ≥ p > 0.2); ** 1.28 ≤ Diff < 1.645 (0.2 ≥ p > 0.1); *** 1.645 ≤ Diff < 1.96 (0.1 ≥ p >0.05); ***(*) Diff = 1.946 (p = 0.052); **** Diff ≥ 1.96 (p ≤ 0.05)

∇ 0.75 < SE_{PCTS}/SE_{OM} ≤ 0.80; ∇∇ SE_{PCTS}/SE_{OM} ≤ 0.75; Δ 1.25 > SE_{PCTS}/SE_{OM} ≥ 1.20; ΔΔ SE_{PCTS}/SE_{OM} ≥ 1.25

Table 3. Results for the four-level null model and for models ignoring one or two intermediate levels

	PCTS		PCS		PS		PTS		PT	
	Estimate	*SE*	*Estimate*	*SE*	*Estimate*	*SE*	*Estimate*	*SE*	*Estimate*	*SE*
Fixed parameters										
Intercept	43.08	1.235	42.84	1.216	42.7	1.194	43.18	1.233	43.66	1.096
Random parameters										
School level	29.11	16.42	42.19.	14.18	61.02***	13.64∇	28.28	16.47		
Teacher level	41.08	15.65					62.26**	15.55	91.82****	15.26
Class level	33.43	6.879	60.37****	9.289ΔΔ						
Pupil level	123.7	3.478	123.7	3.477	167.8****	4.624ΔΔ	139.5****	3.87	139.5****	3.87
Deviance	20884.9		20901		21467.2		21077.7		21082.5	

Diff = | estimate$_{PCTS}$ - estimate$_{OM}$ | /SE$_{PCTS}$
. 0,675 ≤ Diff < 0.84 (0.5 ≥ p >0.4 two sided test); ° 0.84 ≤ Diff < 1.035 (0.4 ≥ p > 0.3);
* 1.035 ≤ Diff < 1.28 (0.3 ≥ p > 0.2); ** 1.28 ≤ Diff < 1.645 (0.2 ≥ p > 0.1); *** 1.645 ≤ Diff < 1.96 (0.1 ≥ p > 0.05; **** Diff ≥ 1.96 (p ≤ 0.05)
∇ 0.75 < SE$_{PCTS}$/SE$_{OM}$ ≤ 0.80; ∇∇ SE$_{PCTS}$/SE$_{OM}$ ≤ 0.75; Δ 1.25 > SE$_{PCTS}$/SE$_{OM}$ ≥ 1.20; ΔΔ SE$_{PCTS}$/SE$_{OM}$ ≥ 1.25

Table 4. Results for the four-level model and for models ignoring one or two top levels (pupil-level variable added)

	PCTS		PCT		PC	
	Estimate	*SE*	*Estimate*	*SE*	*Estimate*	*SE*
Fixed parameters						
Intercept	44.55	0.8885	44.81	0.7963	45.12.	0.6261∇∇
NIQ	0.4611	0.01751	0.4619	0.01749	0.4636	0.01752
Random parameters						
School level	12.92	8.621				
Teacher level	24.61	8.862	37.66**	8.273		
Class level	15.58	3.634	15.55	3.629	52.48****	6.76ΔΔ
Pupil level	101.2	2.844	101.2	2.844	101.2	2.845
Deviance	20282.6		20285.8		20323.2	

Diff = | estimate$_{PCTS}$ - estimate$_{OM}$ | /SE$_{PCTS}$
. 0,675 ≤ Diff < 0.84 (0.5 ≥ p > 0.4 two sided test); ° 0.84 ≤ Diff < 1.035 (0.4 ≥ p > 0.3);
* 1.035 ≤ Diff < 1.28 (0.3 ≥ p > 0.2); ** 1.28 ≤ Diff < 1.645 (0.2 ≥ p > 0.1); *** 1.645 ≤ Diff < 1.96 (0.1 ≥ p >0.05; **** Diff ≥ 1.96 (p ≤ 0.05)
∇ 0.75 < SE$_{PCTS}$/SE$_{OM}$ ≤ 0.80; ∇∇ SE$_{PCTS}$/SE$_{OM}$ ≤ 0.75; Δ 1.25 > SE$_{PCTS}$/SE$_{OM}$ ≥ 1.20; ΔΔ SE$_{PCTS}$/SE$_{OM}$ ≥ 1.25

Table 5. Results for the four-level model and for models ignoring one or two top levels (pupil-level variable and class-level variable added)

	PCTS Estimate	SE	PCT Estimate	SE	PC Estimate	SE
Fixed parameters						
Intercept	45.22	0.7029	45.22	0.6255	45.36	0.4888∇∇
NIQ	0.4285	0.01804	0.4284	0.01804	0.4286	0.01805
CLNIQ	0.5242	0.05887	0.5232	0.05788	0.5661.	0.05709
Random parameters						
School level	7.644	5.351				
Teacher level	14.89	5.624	22.04*(*)	5.114		
Class level	9.032	2.509	9.078	2.521	29.57****	4.112ΔΔ
Pupil level	101.1	2.841	101.1	2.841	101.1	2.841
Deviance	20218		20219.5		20245.5	

Diff = | estimate$_{PCTS}$ - estimate$_{OM}$| /SE$_{PCTS}$

. 0,675 ≤ Diff < 0.84 (0.5 ≥ p > 0.4 two sided test); ° 0.84 ≤ Diff < 1.035 (0.4 ≥ p > 0.3); * 1.035 ≤ Diff < 1.28 (0.3 ≥ p > 0.2); *(*) Diff = 1.27 (p = 0.102); ** 1.28 ≤ Diff < 1.645 (0.2 ≥ p > 0.1); *** 1.645 ≤ Diff < 1.96 (0.1 ≥ p >0.05; **** Diff ≥ 1.96 (p ≤ 0.05)

∇ 0.75 < SE$_{PCTS}$/SE$_{OM}$ ≤ 0.80; ∇∇ SE$_{PCTS}$/SE$_{OM}$ ≤ 0.75; Δ 1.25 > SE$_{PCTS}$/SE$_{OM}$ ≥ 1.20; ΔΔ SE$_{PCTS}$/SE$_{OM}$ ≥ 1.25

Table 6. Results for the four-level model and for models ignoring one or two top levels (pupil-level variable, class-level variable and teacher variables added)

	PCTS Estimate	SE	PCT Estimate	SE
Fixed parameters				
Intercept	45.1	0.7171	45.2	0.5843∇∇
NIQ	0.4285	0.01804	0.4285	0.01804
CLNIQ	0.5422	0.0601	0.5359	0.0588
TJOBSAT	1.184	1.372	1.339	1.444
TPUPILACT	0.05985	1.328	-0.9379.	1.349
TCLASSMAN	0.5931	1.484	0.2753	1.545
TPERSRELP	-0.7458	1.689	-1.052	1.831
TDIFF	1.676	1.433	1.936	1.492
TCONTR	-2.117	1.159	-2.037	1.293
TPERSDEV	2.202	1.771	2.125	2.026
TSUBJMOR	4.926	1.454	4.155	1.626
TDISCIPL	-0.3549	1.468	0.1014	1.622
TPOSDIFF	-0.06666	1.463	-0.06714	1.578
Random parameters				
School level	13.1	5.124		
Teacher level	6.221	3.732	17.93****	4.471
Class level	9.085	2.499	9.063	2.511
Pupil level	101.1	2.841	101.1	2.841
Deviance	20202.3		20207.8	

Diff = | estimate$_{PCTS}$ - estimate$_{OM}$| /SE$_{PCTS}$

. 0,675 ≤ Diff < 0.84 (0.5 ≥ p > 0.4 two sided test); ° 0.84 ≤ Diff < 1.035 (0.4 ≥ p > 0.3); * 1.035 ≤ Diff < 1.28 (0.3 ≥ p > 0.2); ** 1.28 ≤ Diff < 1.645 (0.2 ≥ p > 0.1); *** 1.645 ≤ Diff < 1.96 (0.1 ≥ p >0.05; **** Diff ≥ 1.96 (p ≤ 0.05)

∇ 0.75 < SE$_{PCTS}$/SE$_{OM}$ ≤ 0.80; ∇∇ SE$_{PCTS}$/SE$_{OM}$ ≤ 0.75; Δ 1.25 > SE$_{PCTS}$/SE$_{OM}$ ≥ 1.20; ΔΔ SE$_{PCTS}$/SE$_{OM}$ ≥ 1.25

Table 7. Results for the four-level model and for models ignoring one or two top levels (pupil-level variable and teacher variables added)

	PCTS *Estimate*	*SE*	*PCT* *Estimate*	*SE*
Fixed parameters				
Intercept	44.29	0.8903	44.77	0.7491
NIQ	0.4606	0.01753	0.4614	0.01751
TJOBSAT	1.881	1.756	2.244	1.85
TPUPILACT	0.7435	1.693	-1.146*	1.732
TCLASSMAN	1.042	1.905	0.6214	1.987
TPERSRELP	-0.2488	2.189	-0.7093	2.364
TDIFF	1.349	1.843	1.574	1.918
TCONTR	-4.324	1.472	-4.199	1.636
TPERSDEV	0.4627	2.289	1.37	2.602
TSUBJMOR	3.522	1.878	1.908°	2.067
TDISCIPL	-0.1758	1.899	0.2854	2.083
TPOSDIFF	-0.7508	1.887	-1.631	2.022
Random parameters				
School level	*19.2*	8.139		
Teacher level	13.42	6.377	31.78****	7.335
Class level	15.33	3.573	15.34	3.586
Pupil level	101.1	2.843	101.2	2.844
Deviance	20268		20274.6	

Diff = | estimate_{PCTS} - estimate_{OM}| /SE_{PCTS}

. 0,675 ≤ Diff < 0.84 (0.5 ≥ p > 0.4 two sided test); ° 0.84 ≤ Diff < 1.035 (0.4 ≥ p > 0.3); * 1.035 ≤ Diff < 1.28 (0.3 ≥ p > 0.2); ** 1.28 ≤ Diff < 1.645 (0.2 ≥ p > 0.1); *** 1.645 ≤ Diff < 1.96 (0.1 ≥ p >0.05; **** Diff ≥ 1.96 (p ≤ 0.05)

∇ 0.75 < SE_{PCTS}/SE_{OM} ≤ 0.80; ∇∇ SE_{PCTS}/SE_{OM} ≤ 0.75; Δ 1.25 > SE_{PCTS}/SE_{OM} ≥ 1.20; ΔΔ SE_{PCTS}/SE_{OM} ≥ 1.25

Table 8. Results for the four-level model and for models ignoring one or two intermediate levels (pupil-level variable added)

	PCTS		PCS		PS		PTS		PT	
	Estimate	*SE*	*Estimate*	*SE*	*Estimate*	*SE*	*Estimate*	*SE*	*Estimate*	*SE*
Fixed parameters										
Intercept	44.55	0.8885	44.38	0.8854	44.68	0.8575	44.71	0.8678	44.9	0.7812
NIQ	0.4611	0.01751	0.4612	0.01756	0.5644****	0.01763	0.4982****	0.01738	0.4989****	0.01736
Random parameters										
School level	12.92	8.621	21.73°	7.475	30.35****	6.995∇	11.85	8.267		
Teacher level	24.61	8.862					33.08°	8.473	45.04****	7.735
Class level	15.58	3.634	31.26****	5.103ΔΔ						
Pupil level	101.2	2.844	101.1	2.843	122.3****	3.369	108.4****	3.006	108.4****	3.006
Deviance	20282.6		20300.4		20602.5		20368.2		20371	

Diff = $|\text{estimate}_{PCTS} - \text{estimate}_{OM}| / SE_{PCTS}$

. 0,675 ≤ Diff <0.84 (0.5 ≥ p >0.4 two sided test); ° 0.84 ≤ Diff < 1.035 (0.4 ≥ p > 0.3);

* 1.035 ≤ Diff < 1.28 (0.3 ≥ p > 0.2); ** 1.28 ≤ Diff < 1.645 (0.2 ≥ p > 0.1); *** 1.645 ≤ Diff < 1.96 (0.1 ≥ p >0.05; **** Diff ≥ 1.96 (p ≤ 0.05)

∇ $0.75 < SE_{PCTS}/SE_{OM} \leq 0.80$; ∇∇ $SE_{PCTS}/SE_{OM} \leq 0.75$; Δ $1.25 > SE_{PCTS}/SE_{OM} \geq 1.20$; ΔΔ $SE_{PCTS}/SE_{OM} \geq 1.25$

Table 9. Results for the four-level model and for models ignoring one or two intermediate levels (pupil-level variable and class-level variable added)

	PCTS		PCS	
	Estimate	*SE*	*Estimate*	*SE*
Fixed parameters				
Intercept	45.22	0.7029	45.25	0.7338
NIQ	0.4285	0.01804	0.4289	0.01804
CLNIQ	0.5242	0.05887	0.5661.	0.06012
Random parameters				
School level	7.644	5.351	15.4**	5.046
Teacher level	14.89	5.624		
Class level	9.032	2.509	17****	3.146Δ
Pupil level	101.1	2.841	101	2.84
Deviance	20218		20229.5	

Diff = $|\text{estimate}_{PCTS} - \text{estimate}_{OM}| / SE_{PCTS}$

. 0,675 ≤ Diff < 0.84 (0.5 ≥ p > 0.4 two sided test); ° 0.84 ≤ Diff < 1.035 (0.4 ≥ p > 0.3);

* 1.035 ≤ Diff < 1.28 (0.3 ≥ p > 0.2); ** 1.28 ≤ Diff < 1.645 (0.2 ≥ p > 0.1); *** 1.645 ≤ Diff < 1.96 (0.1 ≥ p >0.05; **** Diff ≥ 1.96 (p ≤ 0.05)

∇ $0.75 < SE_{PCTS}/SE_{OM} \leq 0.80$; ∇∇ $SE_{PCTS}/SE_{OM} \leq 0.75$; Δ $1.25 > SE_{PCTS}/SE_{OM} \geq 1.20$; ΔΔ $SE_{PCTS}/SE_{OM} \geq 1.25$

Table 10. Results for the four-level model and for models ignoring one or two intermediate levels (pupil-level variable, class-level variable and school-level variables added)

	PCTS		PCS	
	Estimate	*SE*	*Estimate*	*SE*
Fixed parameters				
Intercept	45.5	0.6321	45.51	0.6404
NIQ	0.4285	0.01804	0.429	0.01804
CLNIQ	0.5572	0.06064	0.6055.	0.06136
SCOOPTC	-2.314	0.7632	-2.567	0.7798
SDISCSMACQ	-0.3828	0.6115	-0.3723	0.6209
SDIFF	-0.03743	2.202	0.2099	2.247
SPERSP	-0.2775	2.711	-0.2262	2.761
SOLENVICE	0.6695	0.4745	0.4495	0.4685
SCREAINDD	-1.535	0.6711	-1.722	0.6825
SEMDMEDU	0.03505	0.2439	-0.01288	0.2478
Random parameters				
School level	3.619	4.145	9.271**	3.659
Teacher level	12.85	5.101		
Class level	9.201	2.527	16.56****	3.068
Pupil level	101.1	2.841	101	2.84
Deviance	20203.6		20213.6	

Diff = $|\text{estimate}_{PCTS} - \text{estimate}_{OM}| / SE_{PCTS}$

. $0{,}675 \leq$ Diff < 0.84 ($0.5 \geq p > 0.4$ two sided test); ° $0.84 \leq$ Diff < 1.035 ($0.4 \geq p > 0.3$);

* $1.035 \leq$ Diff < 1.28 ($0.3 \geq p > 0.2$); ** $1.28 \leq$ Diff < 1.645 ($0.2 \geq p > 0.1$); *** $1.645 \leq$ Diff < 1.96 ($0.1 \geq p > 0.05$; **** Diff ≥ 1.96 ($p \leq 0.05$)

∇ $0.75 < SE_{PCTS}/SE_{OM} \leq 0.80$; $\nabla\nabla$ $SE_{PCTS}/SE_{OM} \leq 0.75$; Δ $1.25 > SE_{PCTS}/SE_{OM} \geq 1.20$; $\Delta\Delta$ $SE_{PCTS}/SE_{OM} \geq 1.25$

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Table 11. Results for the four-level model and for models ignoring one or two intermediate levels (pupil-level variable and teacher-level variables added)

	PCTS		PTS		PT	
	Estimate	*SE*	*Estimate*	*SE*	*Estimate*	*SE*
Fixed parameters						
Intercept	44.29	0.8903	44.47	0.8663	44.86	0.7307∇
NIQ	0.4606	0.01753	0.4976****	0.0174	0.4983****	0.01738
TJOBSAT	1.881	1.756	1.858	1.704	2.086	1.799
TPUPILACT	0.7435	1.693	0.7847	1.646	-1.007(*)	1.691
TCLASSMAN	1.042	1.905	1.14	1.881	0.6282	1.952
TPERSRELP	-0.2488	2.189	-0.8949	2.182	-1.106	2.335
TDIFF	1.349	1.843	1.255	1.804	1.343	1.87
TCONTR	-4.324	1.472	-4.43	1.425	-4.28	1.579
TPERSDEV	0.4627	2.289	1.011	2.256	1.836	2.538
TSUBJMOR	3.522	1.878	3.797	1.851	2.412	2.02
TDISCIPL	-0.1758	1.899	-0.01211	1.866	0.302	2.03
TPOSDIFF	-0.7508	1.887	-0.6187	1.852	-1.428	1.987
Random parameters						
School level	*19.2*	8.139	17.96	7.762		
Teacher level	13.42	6.377	21.5*(*)	5.934	38.81****	6.71
Class level	15.33	3.573				
Pupil level	101.1	2.843	108.3****	3.005	108.4****	3.006
Deviance	20268		20353.2		20359.6	

Diff = | estimate_{PCTS} - estimate_{OM} | / SE_{PCTS}

. 0,675 ≤ Diff < 0.84 (0.5 ≥ p > 0.4 two sided test); ° 0.84 ≤ Diff < 1.035 (0.4 ≥ p > 0.3); (*) Diff = 1.034 (p = 0.31);

* 1.035 ≤ Diff < 1.28 (0.3 ≥ p > 0.2); *(*) Diff = 1.27 (p = 0.204); ** 1.28 ≤ Diff < 1.645 (0.2 ≥ p > 0.1); *** 1.645 ≤ Diff < 1.96 (0.1 ≥ p >0.05; **** Diff ≥ 1.96 (p ≤ 0.05)

∇ 0.75 < SE_{PCTS}/SE_{OM} ≤ 0.80; ∇∇ SE_{PCTS}/SE_{OM} ≤ 0.75; Δ 1.25 > SE_{PCTS}/SE_{OM} ≥ 1.20; ΔΔ SE_{PCTS}/SE_{OM} ≥ 1.25

Table 12. Results for the four-level model and for models ignoring one or two intermediate levels (pupil-level variable, teacher-level variables and school-level variables added)

	PCTS		*PTS*	
	Estimate	*SE*	*Estimate*	*SE*
Fixed parameters				
Intercept	44.29	0.78	44.47	0.7661
NIQ	0.4606	0.0175	0.4977****	0.01743
TJOBSAT	1.4	1.749	1.3	1.684
TPUPILACT	1.123	1.621	1.213	1.582
TCLASSMAN	0.9968	1.833	1.061	1.805
TPERSRELP	-0.5752	2.1	-1.075	2.095
TDIFF	1.784	1.830	1.495	1.759
TCONTR	-4.13	1.437	-4.228	1.385
TPERSDEV	1.273	2.251	1.891	2.209
TSUBJMOR	4.081	1.84	4.406	1.81
TDISCIPL	-1.247	1.848	-1.092	1.808
TPOSDIFF	0.3661	1.921	0.5278	1.881
SCOOPTC	-0.8439	0.9467	-0.9714	0.9165
SDISCSMACQ	-1.018	0.802	-0.963	0.7947
SDIFF	-4.825	2.885	-4.556	2.808
SPERSP	1.195	3.553	0.6122	3.471
SOLENVICE	1.514	0.6321	1.512	0.6279
SCREAINDD	-1.988	0.9343	-1.94	0.9202
SEMDMEDU	0.1513	0.3383	0.1695	0.3313
Random parameters				
School level	10.52	6.3	10.21	6.072
Teacher level	13.41	6.274	21.16**	5.776
Class level	15.34	3.566		
Pupil level	101.1	2.843	108.3****	3.005
Deviance	20255.2		20340.5	

Diff = | estimate$_{PCTS}$ - estimate $_{OM}$| /SE$_{PCTS}$

. 0,675 ≤ Diff < 0.84 (0.5 ≥ p > 0.4 two sided test); ° 0.84 ≤ Diff < 1.035 (0.4 ≥ p > 0.3;

* 1.035 ≤ Diff < 1.28 (0.3 ≥ p > 0.2; ** 1.28 ≤ Diff < 1.645 (0.2 ≥ p > 0.1); *** 1.645 ≤ Diff < 1.96 (0.1 ≥ p >0.05; **** Diff ≥ 1.96 (p ≤ 0.05)

∇ 0.75 < SE$_{PCTS}$/SE$_{OM}$ ≤ 0.80; ∇∇ SE$_{PCTS}$/SE$_{OM}$ ≤ 0.75; Δ 1.25 > SE$_{PCTS}$/SE$_{OM}$ ≥ 1.20; ΔΔ SE$_{PCTS}$/SE$_{OM}$ ≥ 1.25

Table 13. Results for the four-level model and for models ignoring one or two intermediate levels (pupil-level variable and school-level variables added)

	PCTS		*PCS*		*PS*		*PTS*	
	Estimate	*SE*	*Estimate*	*SE*	*Estimate*	*SE*	*Estimate*	*SE*
Fixed parameters								
Intercept	44.53	0.7886	44.43	0.792	44.8	0.771	44.68	0.7756
NIQ	0.4604	0.01755	0.4608	0.0176	0.5647****	0.01769	0.4976****	0.01742
SCOOPTC	-0.5773	0.935	-0.8375	0.954	-1.291.	0.9092	-0.6392	0.9143
SDISCSMACQ	-0.6683	0.7723	-0.7329	0.7742	-0.5147	0.7938	-0.6033	0.7733
SDIFF	-3.113	2.746	-3.07	2.786	-3.072	2.673	-3.015	2.701
SPERSP	0.3685	3.424	-0.1186	3.457	-1.652	3.37	-0.01622	3.38
SOLENVICE	1.641	0.5885	1.378	0.5742	1.14°	0.568	1.617	0.5848
SCREAINDD	-1.467	0.8489	-1.618	0.8545	-1.604	0.8441	-1.42	0.8459
SEMDMEDU	0.1963	0.308	0.179	0.3099	0.1633	0.306	0.1899	0.3058
Random parameters								
School level	3.924	6.748	13.94**	5.761	23.7****	5.593∇	3.94	6.583
Teacher level	25.54	8.825					33.51°	8.358
Class level	15.63	3.632	31.58****	5.122ΔΔ				
Pupil level	101.2	2.844	101.1	2.843	122.3****	3.369	108.4****	3.006
Deviance	20271.2		20290.1		20592.2		20357	

Diff = $|\text{estimate}_{PCTS} - \text{estimate}_{OM}| / SE_{PCTS}$

. 0,675 ≤ Diff < 0.84 (0.5 ≥ p > 0.4 two sided test); ° 0.84 ≤ Diff < 1.035 (0.4 ≥ p > 0.3;

* 1.035 ≤ Diff < 1.28 (0.3 ≥ p > 0.2; ** 1.28 ≤ Diff < 1.645 (0.2 ≥ p > 0.1); *** 1.645 ≤ Diff < 1.96 (0.1 ≥ p >0.05; **** Diff ≥ 1.96 (p ≤ 0.05)

∇ 0.75 < SE_{PCTS}/SE_{OM} ≤ 0.80; ∇∇ SE_{PCTS}/SE_{OM} ≤ 0.75; Δ 1.25 > SE_{PCTS}/SE_{OM} ≥ 1.20; ΔΔ SE_{PCTS}/SE_{OM} ≥ 1.25

APPENDIX LIST OF VARIABLES

Dependent Pupil Variable

PERCWE1
Percentage of points on a mathematics achievement test measured at the end of the first grade of secondary education. The test is curriculum based and approved by a board of inspectors and teachers.
The reliability is 0.80.

Explanatory Variables

<u>* Pupil-level variable</u>

NIQ
Numerical intelligence measured at the beginning of the school year. The test contains scales of different Dutch and Flemish instruments. The reliabilities of the subscales range from 0.82 to 0.92.

<u>* Class-level variable</u>

CLNIQ
Mean of the numerical intelligence of all the pupils in the class group.

<u>* Teacher-level variables</u>

Name	Description	Number of items and Reliability
TJOBSAT	Job satisfaction of the teacher	n=14 α= 0.87
TPUPILACT	Amount of active pupil participation in the course	n=7 α= 0.77
TCLASSMAN	Amount of orderly classroom management	n=6 α= 0.74
TSUBJMOR	Orientation on subject matter acquisition	n=9 α= 0.70
TDISCIPL	Focus on discipline and obedience	n=9 α= 0.70
TCONTR	Use of control activities (to have the pupils under control)	n=3 α= 0.50
TDIFF	Amount of differentiation activities and material	n=6 α= 0.67
TPERSRELP	Personal relationship with pupils based on trust	n=6 α= 0.67
TPERSDEV	Orientation on the development of the person(ality) of the pupils	n=14 α= 0.77
TPOSDIFF	Positive attitude towards differentiation	n=7 α= 0.68

*** School-level variables**

The school-level variables were constructed on the basis of the reports of a representative sample of teachers on a school characteristics questionnaire. First, orthogonal factor analyses were run to construct scales on the teacher level. We used the mean for the teacher sample of each school (on these scales) to construct school variables. To reduce the number of variables involved, we ran a second order principal component analysis with varimax rotation.

Results of the Component Analysis of Second Order

SCOOPTC: Co-operation of teacher staff in relation to teaching methods and pupil counseling

Scales of Factor Analysis	Component loadings	Description	Number of items and Reliability
AUTTMETH	-0.82	Autonomous versus collective decision making about teaching methods	n=8 α= 0.67
CSTMETH	0.79	Amount of consult with subject teachers about teaching methods	n=10 α= 0.86
PCOUNSEL	0.66	Amount of pupil counseling activities	n=7 α= 0.72
FORMSTRR	0.66	Amount of formal structure and rule setting	n=11 α= 0.69
PUPILRET	-0.54	Pupil retention orientation	n=2 α= 0.70
POSPMS	0.52	Positive attitude towards extern pupil counseling center	n=8 α= 0.89
FUNCTIORG	0.41	Functioning of the school as an organization	n=34 α=0.94

SDISCSMACQ: Focus on discipline and subject matter

Scales of Factor Analysis	Component loadings	Description	Number of items and Reliability
SUBJMOR	0.87	Orientation on subject matter acquisition	n=9 α= 0.70
SOCEDUC	-0.70	Importance of social education	n=7[1]
DISCIPL	0.55	Focus on discipline and obedience	n=9 α= 0.70
CONTR	0.53	Use of control activities (to have the pupils under control)	n=3 α= 0.50

[1] Eight curriculum goals (social education, intellectual education, creativity development, cultural education, emotional development physical education, moral education, vocational training) were presented in pairs. All possible combinations were presented. The respondents had to choose for one goal of each pair. Also an indication of the importance of their choice (much more important, more important, a little bit more important) had to be made

SDIFF: Attention to pupil differences

Scales of Factor Analysis	Component loadings	Description	Number of items and Reliability
ACTPROBL	0.74	Activities undertaken when confronted with a problem pupil	n=5 α= 0.64
DIFF	0.70	Amount of differentiation activities and material	n=6 α= 0.67
PUPILACT	0.64	Amount of active pupil participation in the course	n=7 α= 0.77
CFTPUPIL	0.63	Amount of consult with form teachers about pupil affairs	n=14 α= 0.84

SPERSP: Focus on personality development and personal relationships with pupils

Scales of Factor Analysis	Component loadings	Description	Number of items and Reliability
PERSRELP	0.78	Personal relationship with pupils based on trust	n=6 α= 0.67
PERSDEV	0.63	Orientation on the development of the person(ality) of the pupils	n=14 α= 0.77
POSPARENT	0.64	Positive attitude towards parents and parental involvement in the school	n=10 α= 0.68
USETRES	0.43	Use of test results	n=1

SOLENVICE: Orderly learning environment focused on intellectual and cultural education

Scales of Factor Analysis	Component loadings	Description	Number of items and Reliability
CLASSMAN	0.72	Amount of orderly classroom management	n=6 α= 0.74
CULTEDUC	0.70	Importance of cultural education	n=7
JOBSAT	0.54	Job satisfaction	n=14 α= 0.87
INTELEDUC	0.53	Importance of intellectual education	n=7
HIETRACK	-0.38	Amount of hierarchy between the tracks in the school	n=5 α= 0.71

SCREAIND: Focus on creativity and individual

Scales of Factor Analysis	Component loadings	Description	Number of items and Reliability
CREA	0.81	Importance of developing creativity	n=7
POSDIFF	0.62	Positive attitude towards differentiation	n=7 α= 0.68
TIMESCH	0.38	Amount of time spend on school work	n=1

SEMDMEDU: Focus on education (emotional development and moral education) versus vocational training

Scales of Factor Analysis	Component loadings	Description	Number of items and Reliability
EMODEV	0.78	Importance of emotional development	n=7
FYSEDUC	-0.66	Importance of physical education	n=7
MOREDUC	0.60	Importance of moral education	n=7
VOCTRAIN	-0.51	Importance of vocational training	n=7

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